University of Alberta

Palatally Impacted Maxillary Canines: Factors Relating to Duration of Treatment

by

Dr. Jeffrey A. Stewart

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in

Orthodontics

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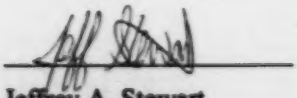

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Abstract

The first objective of this study was to determine the relation that the initial position of a palatally impacted maxillary canine, as seen on a panoramic radiograph, had on the duration of orthodontic treatment. A second objective was to determine whether a difference in treatment duration existed between bilateral and unilateral palatally impacted canine cases.

A total of forty-seven adolescent subjects were chosen, twenty-nine unilateral cases and eighteen bilateral cases. All subjects had full fixed orthodontic appliances placed. The treatment duration of this group was compared to a control group with similar characteristics but without the impacted canine.

The results showed that the average duration of treatment for the control group was 22.4 months, for the unilateral impacted group 25.8 months, while the bilateral impacted canine group had a treatment duration of 32.3 months. The length of treatment for the impacted canine sample was related to the age of the patient at the start of treatment with the younger patients requiring a longer treatment duration. The younger the patient the more severely impacted the canine was found to be. The bilateral impacted canine group had at least one canine more severely impacted than the impacted canine in the unilateral impacted group. At a distance from the occlusal plane of less than 14.0 mm, treatment duration averaged 23.8 months, but if the canine was impacted at greater than 14.0 mm from the occlusal plane, treatment duration averaged 31.1 months.

Life is too short no matter how long you live, so live.

Anonymous

Dedication

This thesis and all of the work which went into it is dedicated to my wife, Tara, and our two beautiful children, Alyssa and Halle, who left our comfortable life in Kelowna for a two year adventure in Edmonton. Their encouragement and support was frequently needed and much appreciated.

To my parents, who gave me encouragement, advice, support and hard work which helped me to become what I am today and will be tomorrow.

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Chapter One

Introduction

And

Literature Review

1.1 - Introduction

The achievement of a normal occlusion is the result of so many interrelated variables that the occasional existence of this ideal would seem to defy the law of probability. Hereditary and developmental, muscular, osseous and dental, systemic and local, physical and emotional, and other factors and combination of factors contributing to the establishment of the occlusion must operate within precise limits. The multiplicity and complexity of these factors are such that the wonder is not that malocclusion exists, but that occasionally there can be found a mouth with no orthodontic problem.

Arthur S. Ash[1]

In most individuals the permanent teeth will erupt into their proper positions and replace their primary predecessors. However, sometimes a permanent tooth is prevented from erupting into the dental arch at its normal time. For this paper the definition of an *impacted tooth* is "a tooth whose eruption is considerably delayed and for which there is clinical or radiographic evidence that further eruption may not take place".[2] Impacted teeth are a frequently encountered clinical problem among patients being treated in a typical orthodontic practice. Considerable interest is attached to the presence of impacted teeth in an orthodontic patient, not only on account of the pathologic conditions they may produce, but also because of their impact on the diagnosis and treatment planning process required for each individual patient.

The type of treatment prescribed for an impacted tooth depends on the particular tooth impacted; the field of specialty of the practitioner first involved, whether a general dentist, periodontist, orthodontist or oral surgeon; and the level of that practitioners' experience with this problem. Such treatment may be as simple as

observation and monitoring, or more complex, including surgical extraction, surgical exposure with or without orthodontic traction (via a variety of methods) or auto-transplantation.

Maxillary canines are one of the most commonly encountered impacted teeth and often present a quandary for the clinical orthodontist. They are considered to be an important tooth esthetically and functionally but impacted maxillary canine cases are perceived to be more difficult and time consuming than the average orthodontic case, requiring more clinical time and a higher fee. Does one try to bring the impacted canine into the arch, commonly assuming that this procedure will add much time and additional patient expense to an average treatment, or does one extract the involved tooth (or teeth), thus saving time and money for the patient, but perhaps at the expense of acceptable esthetics and long term function? How much time will be added and how much extra expense should be charged to the patient?

A determination of the extra treatment time required for a palatally impacted canine, based entirely on subjective clinical experience, is the most often used method in setting the treatment fee and the estimated length of time the patient is told they will be in orthodontic appliances. Often this estimated treatment time is incorrect, with treatment being no more difficult and taking no longer than for an average orthodontic case, or conversely, resulting in the patient wearing their orthodontic appliances far longer than they were initially told and becoming frustrated with their treatment. Additionally, the efficiency of the orthodontic office may be affected if treatment ends up taking far longer and requires many more office visits than the orthodontist first

estimated. The examination of factors which may have an influence on the duration of orthodontic treatment when a palatally impacted canine is involved would be beneficial to both orthodontists and orthodontic patients. It may allow the orthodontist to more accurately answer two of the first questions asked by patients and their parents: "How long will I need to wear my braces?" and "How much is all this going to cost?"

1.2 - Statement of the Problem

In spite of its importance to both orthodontists and patients, very few studies have attempted to evaluate factors which may influence the duration of orthodontic treatment. Fewer studies have evaluated the factors that may affect the duration of orthodontic treatment in cases involving impacted maxillary canines. No studies were found that examined whether the position of the palatally impacted canine, as seen on a panoramic radiograph, or whether the presence of a unilateral or bilateral palatal canine impaction, have an influence on this treatment duration. The investigation of how, or even if, these variables influence the length of time patients will be required to wear orthodontic appliances may be beneficial to clinical orthodontists in more accurately determining office time and cost required in treating these often complex orthodontic problems. A better estimate of treatment duration would also benefit patients in giving them a better idea of their time and cost commitment.

1.3 - Purpose

The first purpose of this retrospective research study is to examine whether the initial horizontal position, vertical position and angulation of a palatally impacted maxillary canine have any influence on the duration of orthodontic treatment in an adolescent sample. The second purpose is to determine whether the presence of bilateral palatally impacted canines will have an effect on treatment duration when compared to unilateral impactions. This will be accomplished by the examination of panoramic radiographs, which are most commonly used by orthodontists to assess the severity of maxillary canine impactions and in making treatment decisions involving these teeth.

Additionally, a pilot study will be done to investigate the reliability of the most commonly used horizontal and vertical reference lines used to quantify the position of the impacted maxillary canine on the panoramic radiograph, as used in recent papers on impacted maxillary canines.

1.4 - Research Questions

1. Is there a difference in duration of orthodontic treatment between an adolescent control sample with no impacted maxillary canine, and an adolescent sample with the presence of at least one palatally impacted maxillary canine?

2. Does the horizontal position, vertical position, and angulation of a palatally impacted canine, as seen on a panoramic radiograph, show a relation to treatment duration?

3. Does the presence of bilateral, as compared to unilateral, palatal canine impactions have a relation to treatment duration?

4a. Is the occlusal plane a reliable horizontal reference line in determining the vertical position of a palatally impacted canine?

4b. Is a line bisecting the long axes of the maxillary central incisors a reliable vertical reference line in determining the angulation of a palatally impacted canine ?

1.5 - Null Hypotheses

1. There is no significant difference in treatment duration between an adolescent sample without an impacted maxillary canine, and a sample with at least one palatally impacted maxillary canine.

2. There is not a significant relationship between the horizontal position, vertical position and angulation of the palatally impacted maxillary canine, as seen on panoramic radiographs, and treatment duration.

3. There is not a significant difference in treatment duration between a bilateral palatally impacted canine case and a unilateral palatally impacted canine case.

4. The most common horizontal and vertical reference lines, as cited in current literature on impacted canines, are not reliable reference lines.

    a. The occlusal plane is not a reliable horizontal reference line for determining the vertical position of a palatally impacted canine.

    b. A vertical line bisecting the long axes of the maxillary central is not a reliable vertical reference line for determining the angulation of a palatally impacted canine.

1.6 - Literature Review

1.6.1 - Theories of Tooth Eruption

Tooth eruption is defined as the movement of a tooth from its site of development within the alveolar process to its proper position in the oral cavity.[3] The mechanism of this eruption is an enigma which has been a matter of long historical investigation, but even today has not been definitively answered.

A variety of theories of eruption have been proposed, but to be considered valid a theory must include the following factual observations in tooth eruption[4]:

1. teeth move in three dimensions as they erupt;

2. teeth erupt with varying characteristic, stage-specific speeds; and

3. teeth arrive at a functional position that is inheritable.

Early theories explained tooth eruption by root elongation or the proliferation of Hertwig's root sheath [3-5] yet it has been shown that rootless teeth, or even metal or silicone replicas, will still erupt.[6,7] However, root elongation may have an influence on the eruption speed of teeth.[4] Other theories which have been studied as causes of tooth eruption include pulpal pressure, pulpal growth, vascular pressure, and traction from fibroblasts.[4]

Recent reviews of eruption[4,8,9] have concluded that eruption is a multifactorial process and that the dental follicle has a pivotal role. Alveolar bone remodelling superior and inferior to the tooth bud, formation and maturation of the periodontal ligament, the presence of blood vessels surrounding the developing tooth, and the presence of various biochemical events all seem to be necessary, at varying stages, for

the eruption of teeth through the alveolar process and into occlusion.

1.6.2 - Incidence of Impacted Teeth

Patients rarely go to their dentist with a chief complaint of an impacted tooth and, since there is often no pain or swelling, they are commonly unaware that this abnormality is present. Generally, it is the family dentist who first observes the presence of a retained primary tooth and then radiographically discovers an impacted permanent tooth. Impacted permanent teeth are a relatively common anomaly among patients seen in a typical orthodontic practice. Mead[10] reported on 1462 full mouth radiographs of "white people" who were patients at his office, with no ages mentioned, and found an incidence of 18.9% having at least one impacted tooth, of which 1.6% were impacted maxillary canines.

Montelius[11] compared Chinese and Caucasian peoples, no ages given, for the incidence of impacted teeth and found the rate of overall tooth impaction to be much higher in Chinese people (31.1%) than in Caucasians (12.2%). Interestingly, though not divided into maxillary and mandibular canines, the rate of canine impaction was far lower for the Chinese (1.7%) than the Caucasian people (5.7%).

In a comprehensive study of 3784 routine full-mouth radiographs, Dachi and Howell[12] found an overall impaction rate of 16.7%, with 0.92% being maxillary canines. Radiographs from 3599 patients who were 20 years and older formed the basis of the study of third molars. An additional 244 sets of radiographs from patients between the ages of 13 and 20 were included in the study of impacted canines and other teeth. All radiographs were from the Indiana University School of Dentistry and

the Dental School of the University of Oregon.

Kramer and Williams[13] studied 3745 panorex radiographs from oral surgery patients at the Harlem Hospital, a mainly Negro population, and reported an 18.2% overall incidence of impaction, with 1.2% being maxillary canines. No age ranges were mentioned in the study.

Using a sample of 7886 patients who visited the Faculty of Dentistry at The University of British Columbia, Shah, Boyd and Vakil[14] found that 546 individuals (6.9%) presented with 918 impacted teeth. Just 0.68% of the total patient sample showed maxillary canine impactions with 7 cases of bilateral impactions and 47 unilateral cases for a total of 61 impacted maxillary canines. Radiographs of individuals seven years and over were analysed to determine the presence of impacted canines.

Grover and Lorton[15] evaluated 5000 panoramic radiographs of U.S. Army recruits, with an age range of 17 to 26 years, and found an incidence of 2.84% impacted maxillary canines. For an overall rate they used a category of unerupted/impacted teeth, and found that 96.5% of the 5000 persons had radiographic evidence of one or more unerupted/impacted teeth.

The tooth most frequently impacted was the third molar, followed by the canine, and the second and first premolars.[10,12-15] The published data showed that the prevalence rate of maxillary canine impaction ranged from approximately 1.0% to 3.0% [10,12-15,24]. Most of the above studies did not separate the location of the impactions into labial and palatal.

The establishment of the incidence between palatal and labial impactions is a

difficult problem. Palatally impacted canines very rarely erupt spontaneously and are usually detected after the age of 12-13 years, the approximate normal time of eruption for these teeth. Labially unerupted canines are usually seen before this age and are often surgically exposed at that time, in conjunction with the start of orthodontic treatment. It is impossible to say that some of these labially displaced teeth would not eventually erupt on their own, albeit in an ectopic location. For this reason, Jacoby[16] recommended that labially displaced teeth be referred to as *unerupted* or *blocked out* and palatally displaced teeth as *impacted*.

Considering the above problem with the establishment of the incidence of labial displacement versus palatal impaction, it is no surprise that the reported incidence varied widely in different studies. In one of the earliest radiographic studies of impacted maxillary canines, Röhrer[17] radiographed 64 patients with 73 displaced maxillary canine teeth and reported a ratio of 3.6:1 palatal to labial.

Hitchin[18] found a rate of 6.6 palatally displaced canines to every 1 labially displaced. Nordenram and Strömberg[19] investigated 374 patients with 500 impacted maxillary canines, age range from 9 to 68 years, and reported a ratio of 1.5:1 palatal:labial.

Thilander and Jakobsson[2], in a widely cited paper, studied 192 boys and 192 girls, mean age 11.5 years, and followed all those with unerupted canines for 7 years. Depending at the age the children were examined, the palatal to labial position ratio varied from approximately 1:6 at the first examination to approximately 2:1 by the last examination. Of the 7 canines which were palatally displaced and unerupted at the first

examination, 5 were still palatally displaced and unerupted at the last examination 7 years later (mean age 18.5 years). The two that erupted were originally classified as "slightly palatally situated". Conversely, of the 41 unerupted canines originally classified as labially displaced at the first examination, only 3 remained unerupted 7 years later. In their adult sample, the ratio was 3:1 palatal:labial.

In a paper presented before the Canadian Association of Orthodontists in 1969, Johnston[20] stated that in his experience "the palatally impacted canines occur almost 50 times as often as labially impacted canines." No data was presented.

Fournier et al[21] reported on 38 teeth treated in their clinic and found a palatal to labial ratio of 3:1. Jacoby in 1979[22] found a ratio of 12:1 palatal:labial, and in 1983[16], with a different patient sample, he reported a ratio of 6.6:1.

Wolf and Mattila[23] radiographed 100 young adults in whom an impacted maxillary canine had been observed on a previous radiographic examination, and found the ratio to be approximately 9:1 palatal:labial.

In another widely cited paper on impacted canines, Ericson and Kurol[24] studied 84 children, ages 10-15 years, with ectopic eruption of 125 maxillary canines. They also found a ratio of palatal to labial displacement of approximately 3:1.

If the subjective statement by Johnston[20] is disregarded, the ratio of palatal impaction to labial displacement of maxillary canines varied between approximately 2:1 to 9:1. [16-24]

1.6.3 - Maxillary Canine Development

The permanent maxillary canine begins calcification at approximately 6-12 months of age, only a few months after the beginning of calcification of the permanent first molars and central incisors, but takes nearly 6 more years to achieve complete eruption.[25] It begins formation between the roots of the first deciduous molars, superior to the crypt of the permanent first bicuspid[26], very high in the anterior wall of the maxillary sinus, under the floor of the orbit[27]. Because of the pyramidal shape of the maxilla, the permanent canine is found palatal to the root of the deciduous canine.[18]

Dewel[28] found that the crown of the upper canine normally varied only a few degrees from vertical but will retain an abnormal inclination once assumed. He felt that this was due to the location of the apex of the root, the length of the root, its time of eruption, and the contours of the crown; these four factors resist any change from that inclination once fully erupted.[28] On the subject of the upper canine, Dewel[29] stated that "Of all teeth it has the longest period of development, the deepest area of development, and the most devious course to travel from its point of origin to full occlusion."

At about 3 years of age, the developing maxillary canine is below the orbit, above the floor of the nose, and between the nasal cavity and the maxillary sinus.[27] By 6 years of age the crown of the canine is at the level of the nasal floor, positioned lingual to the apex of the deciduous canine, and directed mesially.[27] It follows a mesial path of eruption until it reaches the distal aspect of the root of the lateral incisor, and then is guided by the lateral incisor to a more upright position until it is fully in occlusion.

The final position of the canine is largely dependent upon the presence, the proper position and alignment of the lateral incisor. If there is a malposition or malalignment of the lateral incisor, the canine may lose the proper guidance from this tooth and continue to move forward, possibly until it reaches the central incisor root.[27] It may then erupt in a transposed position with the lateral incisor. If the lateral incisor is congenitally missing, the canine may again continue to move medially until it comes in contact with the central incisor and then be guided into the oral cavity, in a more mesial position than normal.[27]

Ericson and Kurol[30] radiographically followed the position of maxillary canines in 41 children aged 8-12 years in whom a clinical investigation had indicated a disturbance in eruption. They found that a difference in palpation of the maxillary canines on the two sides (asymmetry) was a strong indication of aberrant eruption in children 10 years and older, but was not indicative before this age. Early radiographic examination, before the age of 10 years, does not always indicate the final path of eruption. The initial larger investigation on this topic by the same authors[31] suggested that if the canine is palpable on the labial it will erupt, usually in a favourable position. If neither maxillary canine can be palpated in the normal positions and the rest of the occlusal development is advanced, an abnormal path of eruption should be suspected and followed up radiographically. Their last recommendation was that if the lateral incisor is late in eruption or shows a pronounced labial displacement or proclination, it should always be radiographically investigated as this position may indicate a labial ectopic eruption of the canine. This must be differentiated from normal distal tipping of

the lateral incisor during these ages, which has been referred to as the "ugly duckling" stage of development.[25]

Coulter and Richardson[32] used annual lateral and "depressed postero-anterior" (head tilted down 30°) cephalometric radiographs of 30 subjects aged 5-15 years to follow the eruption of the maxillary canines. They found that the canine showed significant annual movement in a posterior direction between 7 and 12 years of age (11.48 mm total); in the vertical plane, maxillary canines showed annual movement between 5 and 12 years of age, always toward the oral cavity (18.56 mm total); and in the lateral plane, these canines showed small palatal movement between 5 and 9 years of age, and then buccal movement thereafter. The total lateral movement ended up being only 2.67 mm between the ages of 5 and 15 years. There was however, because of the initial palatal movement and then buccal movement, an average difference of 5 mm between the most palatal and most buccal positions of the canine crown tip. Using Pythagoras' theorem, these authors have quantified the total movement of maxillary canines, from ages 5-15 years, to be about 22 mm - long and tortuous maxillary canine eruption is indeed!

In a study published in 1998[33], a "transverse retrospective" investigation using panoramic radiographs of 305 children between the ages of 4 and 12 years who had no orthodontic treatment, it was concluded that the upper canine increases its inclination mesially, until a maximum angle of 98° (to a straight line through both suborbitary points, with a range of 85° - 120°) is reached at the age of 9 years, at which point the tooth progressively uprights until it emerges into the oral cavity at approximately 91°.

However, the individual variability of the degree of this inclination at the various ages was considerable and could not be used to predict any abnormal path of eruption. Although common at earlier stages of development, when the development of the lateral incisor was complete, the canine was found to overlap it radiographically in only 7%-11% of the cases. According to these authors, this may be a sign of an eruptive disorder and they suggested preventive measures be taken to avoid permanent canine impaction. Namely, they recommended the extraction of the deciduous canine.

1.6.4 - Sequelae of Impaction

Shafer et al[34] noted the following possible sequelae which can be related to maxillary canine impaction:

1) labial or lingual malpositioning of the impacted tooth;

2) migration of the neighbouring teeth and resultant loss of arch length;

3) internal resorption of the impacted tooth;

4) dentigerous cyst formation;

5) external root resorption of the impacted or neighbouring teeth;

6) infections, especially from partially erupted teeth;

7) referred pain; and

8) any combination of the above.

In addition, Becker[35] mentioned the possibility of resorption of the enamel of teeth that are unerupted over many years. This possible consequence happens mainly in adults and is rare in younger people. However, it is also possible that an impacted

canine may cause no deleterious effects during the lifetime of the person.

The most common, and irreversible, harmful effect of impacted canines seems to be root resorption of the adjacent lateral and/or central incisors.[24,26,36-44] According to Masseler and Malone[45], root resorption was found in approximately 86% of 13,263 permanent teeth examined, and there was no patient who did not have a tooth without root resorption. They concluded that resorption potential varies from person to person, but is not an uncommon finding. Up to 12.5% of ectopically erupting canines caused resorption of the adjacent incisors but this may have been even higher due to the limitations inherent in evaluating resorption with standard intra-oral radiographs.[24]

Linge and Linge[36,41] investigated upper anterior root resorption with standardized intraoral radiographs and found that the 22 cases with an impacted maxillary canine (not distinguished between labial and palatal) showed an average resorption of 2.2 mm on the adjacent lateral incisors. They postulated that this may be due to the increased intrusive force on the lateral incisor as the canine is being extruded orthodontically or may be due to the increased duration of orthodontic treatment when an impacted canine is involved. They also found that the corrected canine very rarely showed any root resorption.

Ericson and Kurol[38-40] found that the incisors will be resorbed mainly with palatally impacted canines and is less common with labial impactions. They found that it may be difficult to diagnose resorption with conventional intra-oral radiographic methods, especially if the canine is overlapping the adjacent incisor. In these cases they recommended the use of polytomography[38] or computed tomography (CT).[40] With

these two methods they could better localize the resorption lesion and found lesions that were not discernible with the conventional radiographs. Most of the resorptions were found in the middle third of the incisor roots and not the expected apical area. The midroot location, together with the fact that lingual and buccal resorptions account for approximately 50% of the lesions, may explain why so many of these resorptions escaped detection with routine periapical radiographs. Resorption of the incisor roots due to ectopic eruption of the canine was most common in the 11-12 year age group, but may occur as early as 9-10 years. The predisposing factors for resorption were stated to be[39]:

1) resorption was three times more common in girls than boys;

2) resorption cases showed a more advanced dental development;

3) the canine was more medial in the dental arch; ie. it was always positioned medially to the midline of the adjacent incisor;

4) the canine showed a slightly more horizontal path of eruption.

Others[42] speculated that the normal-sized and early developing lateral incisor root obstructs the deviated path of impacted canines and have a considerably greater chance of being damaged by resorption than a small or peg-shaped lateral incisor, which may have a shorter[46] and later developing root[47] than the normal lateral incisor.

Another potentially harmful sequelae to canine impaction is the formation of a dentigerous cyst. Sain et al[48] reported on a case where an impacted canine was displaced superiorly to the floor of the orbit due to a large dentigerous cyst.

Other consequences of impacted maxillary canines mentioned in the literature,

summarized by Hitchin[18], include pain, headaches and insomnia, all of which were subsequently 'cured' upon the removal of an impacted canine.

1.6.5 - Etiology of Maxillary Canine Palatal Impaction

In general, the causes for late or slow eruption of teeth may be either generalized or localized.[49] Generalized or secondary causes include abnormal muscle pressures, febrile diseases, endocrine disturbances, and vitamin D deficiency.[49] The most common causes for either labial or palatal maxillary canine displacement are usually localized and any one or a combination of the following factors have been put forth as possibilities, as summarized by Bishara[50]:

1) tooth size-arch length discrepancies;

2) prolonged retention or early loss of the deciduous canine;

3) abnormal position of the tooth bud;

4) the presence of an alveolar cleft;

5) ankylosis;

6) cystic or neoplastic formation;

7) dilaceration of the root;

8) iatrogenic;

9) trauma; and

10) idiopathic, including primary failure of eruption.

More recently, specific to palatal impaction of the maxillary canine, the congenital absence of the maxillary lateral incisor, variation in its root size, and variation in the timing of its root formation[51], or a dental anomaly of genetic origin[52]

have also been suggested as causative factors.

Dewel[28] found that palatally impacted canines occur most often in cases which otherwise present with normal arch form and occlusion of the teeth, with enough space to accommodate them in the arch. He found it odd that such an indispensable tooth, as indicated by the fact that it is almost never congenitally missing and having such a long powerful root, would be displaced so often.

Lappin[26] suggested that the presence of a supernumerary tooth could be a cause of canine impaction but occurs so rarely in the area of the maxillary canine that this is not a significant etiologic factor. He felt that a more important cause may be the position of the canine tooth bud and the long and devious way it has to go to erupt into occlusion. If for some reason the resorptive factors do not attack the deciduous canine root, this could lead to the impaction of the permanent canine. Lappin was one of the first to suggest a genetic component to palatal impaction, as shown by the occurrence of other family members having an impacted canine. Lappin also agreed that crowding of the maxillary dental arch is not a factor in palatal impaction of the maxillary canine.

Fastlicht[53] mentioned the presence of supernumerary teeth, leaning habits, dentigerous cysts, prolonged retention of deciduous canines with septic root canals, or the premature extraction of deciduous canines and molars as causative factors. In contrast to Lappin[26] and Dewel[28], Fastlicht thought that "the deficient mastication in our times with the resultant lack of development of the maxilla undoubtedly" is a factor in maxillary canine impaction, but he also noticed that many impactions occur in well-developed arches. He wrote that the etiology is not yet clear and that some unknown

cause exerts an influence on the displacement of the dental follicle and mentioned that heredity plays a very important role.

Hitchin's[18] investigation into the impacted maxillary canine mentioned etiological factors that included a more labial than normal position of the permanent lateral incisor, thus deflecting the canine palatally; inadequate development of the maxilla, especially in those cases associated with a cleft palate; the early loss of the deciduous canine, but more often the delayed resorption of the root of the deciduous canine; and supernumerary teeth were found to be the main factor in 7 out of 109 maxillary canine impactions he studied.

Thilander and Jakobsson[2] did the first longitudinal study on impacted canines, following 384 adolescents for 7 years, starting with a mean age of 11.5 years. By the end of the study there were only 5 palatally impacted canines which failed to erupt. The position of the tooth was found to be the most important factor for non-eruption - if the tooth was palatal to the lateral incisor, it tended to stay there and not erupt into the oral cavity. The lack of resorption of the deciduous canine was found by these authors to be a result rather than a cause of impaction of the permanent canine. They found no convincing evidence that an enlarged follicular sac was the cause of impaction. Severe crowding generally resulted in a labial displacement of the canine.

Takahama and Aiyama[54] performed a cephalometric radiographic study of 408 parents of patients with clefts and 2959 parents of non-cleft patients, and concluded from their results of a significantly higher incidence of upper canine impaction in the cleft group fathers, that maxillary canine impaction may be a possible microform of

cleft lip and palate.

The purpose of Jacoby's work[16] was to establish the relationship between arch length and canine impaction by separating the labial impactions from the palatal impactions. In this study, 85% of the 40 palatally displaced canines had sufficient or excess space in the arch to erupt. Two of the palatal canines (5%) were thought to be related to agenesis of the ipsilateral lateral incisor, while four (10%) were thought to be related to peg-shaped lateral incisors. Two of the palatal canines in which there was not sufficient space in the arch occurred in the same patient who the author felt had a general hypodevelopment of the skeletal tissues and had some hidden symptoms of cleft palate. Of the remaining four palatally impacted canines without sufficient space in the arch, two of the patients had the opposite maxillary canine labially displaced, while one other had a crossbite on the side with the palatally impacted canine. In contrast, only one of the labially displaced canines showed sufficient space in the arch for the canines. Jacoby felt that it is evident that arch-length deficiency is the major etiologic factor in labially displaced canines. In contrast, he stated that excessive space in the maxillary canine area could allow the canine to move palatally in the bone and find a place behind the buds of the other teeth and eventually become palatally impacted. Jacoby suggested that labially displaced canines be referred to as *unerupted* while the term *impacted* be used only for palatally displaced canines.

Sain et al[48] described a case of a maxillary canine which was impacted and displaced through the maxillary sinus and superiorly to the floor of the orbit by a dentigerous cyst. The patient initially came in with a chief complaint of the delayed

eruption of a permanent maxillary central incisor, and only after a radiographic examination was the impacted canine seen. After resolving the cyst the impacted canine was brought into occlusion.

Brin, Solomon and Zilberman[35] presented two cases of trauma to the anterior area of the mouth that eventually resulted in an impacted canine on the affected side. In one case the trauma resulted in shortening of the root of the lateral incisor which these authors felt affected the path of eruption of the adjacent canine tooth. In the other case presented, the trauma produced a misalignment of the anterior segment which caused the lateral incisor to lose "the desirable relationship with the adjacent canine bud at a critical stage of dental development." They recommended that special attention should be paid not only to the teeth directly injured by the trauma, but also to the development of apparently unharmed neighbouring teeth.

McConnell and colleagues[36] investigated whether patients with impacted canines have a transverse maxillary deficiency and whether other factors, such as arch length, arch perimeter or arch form contributed to the incidence of impacted maxillary canines. They did not separate labial and palatal impactions for their results but did show a 2.5:1 ratio of palatal to labial impactions. They found that patients with canine impactions do have a transverse maxillary deficiency in the anterior part of the dental arch compared to a control group, but arch form, arch perimeter, arch length and intermolar width did not significantly contribute to the incidence or location of canine impaction.

Today, the two major theories regarding the most common cause of palatal

impactions of maxillary canines are the 'guidance theory' and the 'anomaly of genetic origin'. The guidance theory suggests that a proper size and timely formation of the adjacent lateral incisor root is required to guide the erupting canine to its proper location in the arch. Should this root be smaller than average or late in formation then the canine has a greater chance of becoming displaced palatally. The anomaly of genetic origin theory suggests that palatal displacement is a positional anomaly of the canine follicle, occurs with other dental anomalies and is very often familial.

In their study of 7886 British Columbian individuals, Shah et al[57] found an incidence of congenitally missing teeth of 3.56%, including third molars. Of these missing teeth, approximately 13% were maxillary lateral incisors, for an approximate total of 0.5% incidence of congenitally missing lateral incisors in this population. When third molars were excluded, the incidence of missing teeth drops to only 1.82%. They also found an incidence of 0.32% for the occurrence of peg teeth. These authors quoted other studies, on different populations, which showed an incidence of between 0.5% and 8.4% for peg-shaped lateral incisors.

Miller[58] noted that the congenital absence of the adjacent permanent lateral incisor has an influence on the eruption of the canine. He felt that the smaller root of the retained deciduous lateral incisor allows the canine to pass medially over its apex and then become palatally impacted.

Becker, along with various colleagues, has done much research on the incidence of anomalous maxillary lateral incisors in relation to palatally displaced canines. In an early publication, Becker at al[51] obtained 55 cases of palatally displaced canines from

633 consecutive patients from an orthodontic practice and an additional 33 cases fulfilling the same criteria from the orthodontic department of a dental school and another private practice. They classified the lateral incisors adjacent to the palatally impacted canine as absent, peg-shaped, small (mesio-distal width equal to or smaller than its mandibular counterpart), or normal. Their results showed that females were affected with a palatally displaced canine 2.5 times more than males, and in 45% of all cases the impaction was bilateral. These researchers found that in almost half the cases (48%) the adjacent lateral incisor was either absent or of an anomalous size. They believed that small or peg-shaped lateral incisors tend to develop later than normal and are insufficiently developed to provide critical guidance in the very early stages of development and migration of the canine. Absent lateral incisors are obviously also unable to provide this needed guidance. They found that their 5.5% rate of congenitally absent lateral incisors in their palatal canine population was much higher than that seen in the general population (2.1% in a Jewish population that they quoted, 0.5% in a Canadian population[57]). Becker et al[51] suggested that there appear to be two processes in the palatal displacement of the maxillary canine. The first is a developmental one where the absence of guidance by the congenitally missing, late-developing, or small-rooted adjacent lateral incisor allows the erupting canine to move towards the palatal side. The second one related to a later period, when the canine is moving down into the narrower part of the alveolus and then is prevented from its normal labial movement by the roots of the permanent lateral incisor.

An evaluation of 70 palatally displaced canines and 106 controls done by

Becker and others[46] found the average length of lateral incisors adjacent to a palatally displaced canine to be 2.12 mm shorter than those adjacent to normally erupted canines, with 1.4 mm of this discrepancy attributable to a shorter root. The length of the central incisors was not found to be significantly different in the two groups. They concluded that there is a definite link between small lateral incisor crown size and the incidence of palatal displacement of the adjacent canine; there is a link between a short lateral incisor root and the incidence of palatal displacement of the adjacent canine; and there is a definite link between lateral incisor crown size and root size. They thought that the shorter root, together with the lateness of development of anomalous teeth, deprive the canine of needed guidance in the early stages of development.

Brin, Becker and Shalhav[59] examined a random sample of 2440 adolescents (1173 males and 1267 females) and found a rate of 7.1% of missing or anomalous lateral incisors (as classified in their earlier study above), and a rate of 1.53% for palatally impacted canines. There was no statistical difference between females and males for either palatally displaced canines or absent or anomalous lateral incisors. They found that almost 43% of the palatal canines were associated with anomalous or missing lateral incisors. They calculated that there is a 0.98% probability of a palatal canine adjacent to a normal lateral incisor, an 11.5% chance of a palatal canine adjacent to a peg-shaped lateral incisor, 9.8% when a small lateral incisor is present and 5% when the lateral incisor is congenitally absent. These authors reported that 72.6% of the palatal canines were found in an Angle Class I malocclusion, 20.5% in a Class II malocclusion, and only 6.8% were found in a Class III malocclusion.

Since these anomalies of lateral incisor development are known to be under strong genetic control, Zilberman, Cohen and Becker[60] investigated whether first degree relatives of patients with palatal canines would exhibit an increased prevalence of the anomalies. Of the parents of these patients examined, 5.1% were found to have palatal canines with 30.8% having absent or anomalous lateral incisors. Of the siblings examined, 11.4% were found to have palatally displaced canines and 28% showing a developmental problem with lateral incisors. These findings in the parents and siblings are considerably higher than in the general population studied previously by these researchers (1.5% palatal canines, 7.1% anomalous or missing lateral incisors).

Others have also studied whether there was a relation between a palatal canine and an adjacent small or peg-shaped lateral incisor. Using a Scottish population, Mossey et al[61] undertook a retrospective study of 182 subjects from records of orthodontic patients with palatally displaced canines. Eighty percent of the subjects had a unilateral impaction and twenty percent had bilateral impactions. All twenty-three of the peg-shaped lateral incisors were associated with a palatally impacted canine, and there were twice as many small laterals on the affected side. Twenty-three subjects had thirty-three congenitally absent lateral incisors, with only nineteen of the absent laterals related to a palatally displaced canine. In contrast to the findings of Becker et al[46], Mossey's group found no association between a smaller lateral incisor crown size and a shorter root length. This group found that 56% of the subjects had a Class I malocclusion, 29% a Class II division 2 malocclusion, 9% a Class II division 1, and only 6% a Class III malocclusion.

Oliver and colleagues[62] studied a Caucasian group of 31 subjects and an Oriental group of 29 subjects, both from a dental school population, who showed the presence of unilateral maxillary canine impaction. They found that crowding in the Oriental population was significantly greater than in the Caucasian sample, and that most of the canine impactions in the Oriental population were to the buccal while most of the Caucasian impactions, which had less crowding, were to the palatal. They concluded that a lateral incisor adjacent to an impacted canine is slightly, though statistically insignificantly, narrower and shorter than the contralateral incisor, but this should be considered with care due to the small sample size.

In the other major alternative theory regarding palatal impaction of the maxillary canine, Peck, Peck and Kataja[52] argued that this malocclusion is a positional variation which develops due to genetic factors and not due to local factors such as retained deciduous canines, anomalous lateral incisors or dental crowding. Peck et al[52], in a review of the literature, grouped their evidence into five categories:

1) Occurrence of other dental anomalies concomitant with PDC (palatally displaced canines)

It is known that a genetic etiology exists for at least three of the abnormalities associated with PDC: tooth agenesis, generalized tooth size reduction, and systematic lateness of tooth development. Peck et al[52] mentioned that another positional anomaly of the maxillary canine, transposition with the first premolar, also occurs with a high frequency in combination with the above specific anomalies and, like them, it also appears to be of genetic origin. They suggested that the evidence clearly points to the idea that PDC is not an isolated phenomena but that it frequently occurs in association

with other genetically interrelated dental anomalies.

2) Bilateral occurrence of PDC

Peck et al[52] listed ten other studies which reported bilateral occurrences of PDC, ranging from 17% to 45% of the total number of cases in each study. They stated that this rate is far beyond chance occurrence and points to an intrinsic etiology such as a genetic mechanism. This rate appears to be similar to rates of bilateralism of other dental anomalies under genetic control, such as maxillary lateral incisor agenesis, with a rate of 29% to 46% of cases, and maxillary canine-first premolar transposition with a bilateral occurrence of 23% to 43% of cases studied.

3) Sex differences in PDC occurrence

Sex ratios are useful in identifying biological phenomena with genetic links involving the sex chromosomes. The male-female ratios of PDC occurrence ranged from M1:F1.3 to M1:F3.2 in the ten studies listed in their paper[52], which compare favourably with sex ratios recorded for other dental anomalies of genetic origin, such as hypodontia (M1:F1.3 to M1:F1.6) and maxillary canine-first premolar transposition (M1:F3.8).

4) Familial occurrence of PDC

Results of family studies[52] have shown evidence of increased rates of occurrence of PDC among other family members. Two of the studies suggested a genetic transmission for the PDC anomaly with only the study by Zilberman, Cohen and Becker[60] not subscribing to this theory. They supported the theory of a genetic anomaly of the lateral incisors resulting in a lack of guidance for the canine, which mechanically results in a palatal impaction.

5) Population differences in PDC occurrence

Peck et al[52] reported that a dichotomy exists in PDC prevalence between Europeans and those of African or Asian ancestry. Most of the cases reported in the literature for PDC are from those with a European background and reports of PDC are rare in African and Asian dentitions. They calculated the prevalence rate ratio for the occurrence of PDC in Europeans to Asians to be European 5: Asian 1. They suggested that these racial differences of PDC occurrence support the genetic involvement in the etiology of this anomaly, similar to other orofacial anomalies with a racial predilection, such as cleft lip/palate and maxillary canine-first premolar transposition.

Peck, Peck and Kataja[52] suggested that early theories of palatally displaced canines such as retained deciduous canines or inadequate arch length are no longer viable in light of more recent research. They also suggested that the presence of an anomalous lateral incisor or a congenitally absent incisor along with the palatally displaced canine suggests nothing about causality, but that they are simply "coincident traits appearing within the context of a larger, biological mechanism of control, namely, genetics." However, they stated that the basis of genetics for this anomaly does not rule out the occasional influence of environmental factors such as early dentofacial trauma in the genesis of some palatal impactions.

Soon after the above publication, Dr. Adrian Becker[63] wrote a letter to the editor of 'The Angle Orthodontist' disputing the conclusions of Peck et al[52], which was then replied to by Peck, Peck and Kataja[63]. These two letters quoted much of the same research on palatally impacted canines to defend their individual theories but

arrived at different conclusions as to the cause. Whichever view turns out to be correct it appears that genetics is involved, either involving only the lateral incisors and subsequent lack of mechanical guidance for the canine, or having a larger role and being responsible for the abnormal position of the canine, the anomalous size or absence of the lateral incisors, and other anomalies which may occur with a palatally impacted canine.

1.6.6 - Diagnosis and Localization of Impaction

The diagnosis and localization of canine impaction is based on clinical, digital and radiographic examinations. Bishara[50], in one of his reviews on maxillary canine impactions, listed the following clinical signs which may be indicative of canine impaction: (1) delayed eruption of the permanent canine or prolonged retention of the deciduous canine beyond 14 to 15 years of age; (2) absence of a normal labial canine bulge; either inability to locate the canine position through intraoral palpation of the alveolar process or the presence of an asymmetry in the canine bulge noted during alveolar palpation; (3) presence of a palatal bulge; (4) delayed eruption, distal tipping, or splaying of the lateral incisor.

Most authors agreed that maxillary canines have usually erupted into full occlusion by approximately 12 years of age[18,25,28,53]. After this age the absence of a canine in the arch, without a history of extraction, usually suggests that it is impacted. Very rarely is a maxillary canine congenitally absent. According to Ericson and Kurol[31] the absence of the 'canine bulge' before the age of 10 years, in most cases, is not indicative of any eruption problems with the canine. Because of individual variation in

tooth development and eruption, general somatic maturity and dental development are considered more important than age when assessing the need for a radiographic assessment. In their evaluation of 505 school children, aged 8-12 years, they found that at 10 years of age 29% of the children had non-palpable canines, only 5% at 11 years of age, and only 3% at later ages. They recommended the following indications for radiographs: 1) asymmetry on palpation or a pronounced difference in eruption of canines on the left and right sides; 2) the canines cannot be palpated in the normal positions and the occlusal development is advanced; 3) the lateral incisor is late in eruption or shows a pronounced buccal displacement or proclination.

Others[27,65,66] suggested that the inclination of the lateral incisor may give a clue to the position of the unerupted canine. A distal inclination of the lateral incisor (ugly duckling stage) indicated a close relationship of the canine crown to the incisor apex. If the lateral incisor crown has a labial tilt then the crown of the canine will often be found on the labial aspect of its root. Palatal displacement of the canine usually does not affect the position of the lateral incisor but in some cases the latter tooth will be retroclined, possibly in crossbite. Mobility of the lateral incisor suggests resorption of its root, often due to malposition of the canine.

In summary, where it is not possible to palpate the canine by about ten years of age, and an ectopic path of eruption is suspected, then radiographic assessment is necessary to localize the canine.

Röhrer[17] gave a very early, detailed description of taking and reading radiographs to localize the position of displaced and impacted teeth. Hitchin[18], before

the invention of the panoramic radiograph, recommended lateral intraoral films at different angulations, occlusal films, and/or lateral and postero-anterior cephalometric films to localize the impacted tooth.

Most contemporary papers[67-69] recommended the use of two intraoral periapicals at different angles (parallax method, Clark's method, tube-shift method, buccal object rule) to easily determine whether a tooth is buccal or lingual to another tooth, and/or using occlusal films along with a panoramic radiograph to locate the spatial position of the impacted tooth.

A few publications have investigated using only a panoramic radiograph to localize an impacted maxillary canine. Wolf and Mattila[23] took a series of panoramic radiographs on 100 young adults with 116 impacted canine teeth. More than 80% of the teeth in a horizontal or mesio-angular position, in relation to the occlusal plane, were situated on the palatal side with less than 20% located labially or in the middle of the alveolus. In contrast, of the teeth in a vertical position, only one was situated on the palatal aspect of the arch. All 45 cases in which the canine crown was projected at the site of the root of the central incisor were located palatally. Of the canines located at the site of the lateral incisor about 75% were palatally positioned. Of the fifteen canines located in the proper position mesio-distally, only 13% were palatally displaced, with 60% centrally located and the rest labially displaced.

When trying to determine the labio-palatal position of the impacted canine from panoramic radiographs on the basis of magnification, knowing that a palatally impacted tooth will be magnified more and appear larger than one in the line of the arch or

labially displaced, a dental radiologist made a correct assessment in 88% of the cases while another radiologist correctly assessed 89% of the cases. The greatest accuracy was achieved with regard to palatally located teeth, which were correctly identified in 95%-99% of the cases. However, these authors[23] concluded that the determination of the labio-palatal location of impacted teeth based on a single panoramic radiograph was unreliable and the method was not suitable for clinical use.

Another investigation[70] used only panoramic radiographs from100 patients to localize impacted maxillary canines. These authors concluded that correct prediction of palatal unerupted maxillary canines using differential magnification on panoramic radiographs was possible in about 80% of the cases. They also recommended that further radiographs are required to localize the position of the impacted canine with more certainty.

A recent study[143] had the objective to develop a reliable method of diagnosing the position of a displaced canine on the basis of a single panoramic radiograph. They used a ratio of the width of the impacted canine to the width of the homolateral central incisor and found that the panoramic radiograph can serve as a useful indicator for determining the position of an unerupted maxillary canine in some instances. However, in many cases other radiographs were still necessary.

Jacobs has published prodigiously on the subject of localizing impacted canines.[71-75] He suggested that there are three accurate radiographic methods of localization: (1) the parallax method; (2) the use of two radiographs taken at right angles to each other; (3) stereoscopy. The parallax method (tube shift, Clark's rule,

buccal object rule) is the most widely used technique and can be done via a horizontal tube shift or a vertical tube shift.

1.6.7 - Prevention/Interception of Maxillary Canine Impaction

It would seem to be a wise course of action to prevent or intercept the impaction of the maxillary canine and prevent the detrimental sequelae which can occur due to this anomaly. Broadbent, in a communication to Lappin[26], demonstrated by taking a series of anteroposterior and lateral headfilms of children, starting at the age of 6 years, and at intervals of 3-6 months, that it is possible to observe with great accuracy the path of eruption of the permanent canine. By noting deviations from normal, Broadbent could predict an abnormal eruption path of the permanent canine and would then remove the deciduous canine so that the permanent canine could then assume its normal position and not become palatally impacted. This would be an effective solution to prevent canine impaction but it is no longer ethical to take radiographs every 3-6 months on children to monitor the remote possibility of an impaction occurring.

Williams[68] recommended the dental age of 8 years to be the best time to begin observation of the intra-bony eruption of the canine for detection of possible complications. In Class I uncrowded malocclusions where maxillary canine bulges are absent, he recommended radiographs to ascertain the position of the permanent canines. If the canine appeared to have a mesial tilt and a position lingual to the incisor teeth, Williams suggested the removal of the deciduous canine. The extraction of the deciduous canine can also be helpful at later ages, but he said that the final

improvement in the permanent canine position may not be as successful as that seen at the earlier ages.

Recommendations by Ngan et al[76] included observation of the intrabony movement of the maxillary canine between the ages of 8 and 10 years, and early extraction of the primary canines to help redirect the path of eruption of the permanent canines if a problem is suspected.

In a frequently cited paper on the prevention and interception of maxillary canine impaction, Ericson and Kurol[77] followed 46 ectopic maxillary canines in 35 individuals, ages 10 - 13 years, in the first prospective longitudinal study on the prevention of palatal impaction. All cases showed no or minimal space problems. In all of the cases the primary canine was extracted, with the result that 78% of the permanent canines showed a change to a normal eruption from the previously palatal position, most within 6 months and all within 12 months. None of the other cases normalized after 12 months. Their results showed that, in this age group, 91% of the canines normalized when the permanent canine crown was distal to the midline of the lateral incisor. Conversely, the success rate fell to 64% when the permanent canine crown was mesial to the midline of the lateral incisor. In contrast to earlier publications, Ericson and Kurol[77] recommended that before the age of 10 years, spontaneous correction of potentially displaced maxillary canines may occur and extraction of the deciduous canine is normally not indicated, unless the patient shows very early dental maturity. Extraction of the deciduous canine is the treatment of choice in the age group 10 - 13 years when the permanent canine has a palatal ectopic eruption path.

Jacobs[78] published two case reports which followed the guidelines of Ericson and Kurol[77] which were both successful in intercepting a potential palatal impaction of maxillary canines. Jacobs[79] also published two case reports which were outside the guidelines of Ericson and Kurol[77] but which were also successful in correcting the path of eruption of palatally displaced canines. This latter study suggested that extracting the primary canine and allowing 12 months of observation to see if the permanent canine does correct its path of eruption may be worth trying in most palatally impacted canine cases.

In a more recent prospective study[80], 39 consecutive patients with 47 palatally displaced canines, age range 9.3 - 14.5 years, were followed for two years after the extraction of the deciduous canine. Two patients aged 9.3 years showed early dental development and the 14.5 year old showed late dental development. Overall 62% of the canines achieved a normal eruptive position, 19% showed some improvement and a further 19% failed to improve or their position deteriorated. Of the 17 permanent canines which were mesial to the midpoint of the adjacent lateral incisor, only 5 successfully erupted into position (29% success compared to Ericson and Kurol's 64% success[77]). Of the 22 canines that overlapped the adjacent lateral incisor root by half or less, 16 (73%) were successfully normalized. When no overlap was present there was a 100% success rate. A reported trend was that the chance of a successful return of the canine to a normal eruptive pathway decreased if the original canine angulation exceeded 31 degrees. However, the angulation effect exerted less influence on the chance of success than the degree of overlap of the adjacent incisor root. Vertical

height and eruptive distance were not found to be significant factors.

1.6.8 - Treatment Alternatives

Once a palatally impacted maxillary canine has been diagnosed and localized, and any preventive/interceptive measures have failed in normalizing the position of the tooth, some type of active treatment is indicated. There are many proposed treatment alternatives for the correction of the palatally impacted canine in the literature. Consideration needs to be given to the attitude of the patient, the space present at the canine site and in the arches generally, the general state of the dentition, mobility and/or resorption of adjacent teeth, the position of the canine, the presence of a dilaceration of the root of the impacted canine, the age and health of the patient, and surgical difficulties and/or contraindications to surgery. Some of the more common methods of treating a patient with a palatally displaced maxillary canine, as summarized by Bishara[30], include:

1) No treatment.

2) Extraction of the impacted canine and movement of the first premolar into its position.

3) Extraction of the impacted canine and prosthetic replacement of the canine.

4) Extraction of the canine and a segmental osteotomy to move the buccal segment mesially to close the space.

5) Surgical exposure, allowing natural eruption to occur.

6) Autotransplantation of the impacted canine.

7) Surgical exposure of the canine with orthodontic treatment to bring the

canine into proper occlusion.

The patient may not wish to consider treatment of the impacted canine if they feel that their appearance is satisfactory with the deciduous canine in place. In these cases the patients need to be warned of the possible sequelae of leaving the impacted tooth in the alveolus, and of the need for periodic radiographic monitoring of the retained impacted permanent canine.

The patient may opt for the removal of the impacted canine, to prevent some of the possible problems from occurring, but leaving the deciduous canine in place. They must be advised that the prognosis for the deciduous canine lasting for their lifetime is slim, and that some prosthetic dental treatment or orthodontic treatment will probably be needed in the future.

One non-invasive technique to bring palatally displaced canines into the arch was stated to have a 66% success rate with proper case selection.[81] The technique consisted of continuous light pressure on the soft tissues overlying the impacted canine, effected by the use of a removable appliance with an expansion screw angulated in the direction in which the canine must move to align itself in the arch. The author stated that the normal eruptive forces seemed to be stimulated to cause the tooth to erupt into occlusion. Age did not seem to be a prohibitive factor, but it was suggested that the 11 to 16 year age group holds the most chance of success.

Allowing free physiologic eruption of an impacted tooth, before orthodontic appliances are placed, was recommended by some authors.[26,82,83] The oral surgeon exposes the palatally impacted canine and removes all of the surrounding soft tissue

and as much of the surrounding bony crypt as is practical, without exposing the cemento-enamel junction of the impacted tooth or damaging the roots of adjacent teeth. The surgeon then either places a surgical pack to prevent tissue overgrowth of the exposed tooth[17,83] or cements a plastic crown form over the canine.[82] A channel can also be placed in the bone towards the deciduous canine to aid in the movement of the permanent canine in this direction[82]. The proponents of this method stated that most of the teeth treated with this method erupted sufficiently within 6-12 months to proceed with full orthodontic therapy, a savings of 6-12 months of time in orthodontic appliances, expense and inconvenience to the patient.

In those rare cases where dental crowding is part of the diagnosis in a palatally impacted canine case, or if extractions are required for improved facial esthetics, consideration must be given to extracting the impacted permanent canine and the deciduous canine and replacing the space with the adjacent first premolar. Many orthodontists traditionally attempt to bring the impacted canine into position because of their feelings on the importance of the canine to function and esthetics. However, because this procedure is not guaranteed, it is advised that any extraction of a premolar be delayed until the prognosis of bringing the canine into position is more certain. Nonetheless, in some cases the extraction of the canine is the better idea due to its position of impaction where attempting to bring it into occlusion could damage adjacent tooth roots, presence of ankylosis, if it is undergoing external or internal root resorption, age of the patient, or excellent alignment of the existing premolar in the canine position. In some cases this premolar substitution can be quite acceptable, with

little compromise in either esthetics or function. Perhaps due to the pervasive thought among orthodontists on the importance of the canines, there is little literature on the substitution of premolars for canines.[84,85]

Occasionally, the extraction of the impacted canine with prosthetic replacement will be the best choice of treatment for the patient. This may be due to a perceived social stigma to wearing orthodontic appliances as an adult, or limited problems in other areas of the mouth requiring a relatively short duration of orthodontic treatment, and the extra time required to close the space or bring the canine into the arch is not desired by the patient. As long as the patient understands the limitations of prosthetics, potential future replacements required, and potential problems of prosthetics, this is a viable option to replacing an impacted canine. Autotransplantation is a little used technique in North America to place an impacted tooth into its proper position but does have a good success rate when cases are carefully selected.[86-89] A very similar technique, called 'repositioning' or 'surgical alignment' [90,91], is when the impacted tooth is surgically moved into the arch but is not removed from the tissues during treatment. Instead, it is rotated about its apex into the proper position.

The most common method of bringing palatally impacted canines into occlusion is via surgical exposure, affixing some kind of attachment to the canine, and orthodontically pulling the tooth into the arch. There are many ways which have been used to place an attachment on the impacted canine to provide the force to bring it into the line of occlusion. These include cementing a pin into a hole drilled in the incisal edge of the canine[92,93], fabricating a cast onlay or band with a loop to cement over the

exposed canine[20,33,94], cementing a celluloid crown form with a piece of band metal inserted into a slot in the crown form to which traction can be exerted[95], tying a ligature wire around the canine crown[67,96,97], cementing a preformed orthodontic band[98], embedding a wire loop into a prepared cavity in the crown of the impacted tooth and filling the cavity with restorative material[99], and cementing a button on to the dry impacted canine with Durelon.[100] Today, the most common method of fixing an attachment to an impacted canine is to etch the dry tooth with acid and bond a button, eyelet or orthodontic bracket directly to the tooth, either at the time of surgery or soon thereafter.

However the attachment is made to the tooth, a force must then be applied to bring the impacted canine into position. Some [21,101-103] recommended the use of a removable appliance and elastics to apply the force, reasoning that it is more economic and provides better control of the force direction than full banding.

Vardimon et al[104] recommended the use of a magnet bonded to the canine and an attracting magnet in a removable acrylic appliance to erupt the impacted canine into occlusion. These authors felt that this replicates normal eruption better than other methods, involves a less invasive surgical procedure, provides for well-controlled spatial guidance, and decreases the hazards of bone loss and root resorption. Sandler[105] also advocated the use of a magnetic system as a modern alternative approach in the eruption of impacted teeth.

Bishara[30] summarized some of the methods of applying traction to an impacted tooth, which includes the use of light wire springs soldered to a heavy labial or palatal

base wire, or directly to molar bands, mousetrap loops, or a 'ballista spring'.[22] Some of the newer orthodontic materials have expanded the repertoire of materials which can be very effective in moving an impacted tooth, such as elastic threads, elastomeric chains, nickel titanium springs and nickel titanium wires. The methods of applying a traction force to a palatally displaced canine are now limited only by the imagination of the orthodontist![53,66,97,99,100,106-111]

Early methods of surgical exposure of impacted canines endorsed extensive bone removal to expose the crown of the impacted tooth, mainly for access to place a cast crown or steel ligature on the crown, but also to provide an easier path for tooth movement. The exposure was left open and packed with surgical paste, or a crown form was cemented over the crown of the impacted canine until the soft tissue healed, some natural eruption occurred, and the tooth was then orthodontically brought into occlusion.[53,92]

McDonald and Yap[103] stated that it is not the amount of bone removed that is important, but the manner in which the soft tissues are handled, in particular the periosteum, that ultimately affects the results of the surgical treatment.

In contrast, Kohavi, Becker and Zilberman[111] compared the health of the supporting tissues of impacted canines exposed with a "heavy" exposure or a "light" exposure. They summarized their findings by stating that the most serious damage that occurs in the treatment of palatally impacted canines is the result of surgical intervention which exposes the cementoenamel junction of the impacted tooth. This damage is in the form of loss of supporting tissues, including bone support, of the

previously impacted canine.

Today, the two techniques of surgically exposing and bringing the palatally impacted canine into occlusion are the 'open eruption' and the 'closed eruption' techniques. Both techniques require the least amount of bone removal that is necessary to bond an attachment to the crown of the impacted canine.

The open eruption technique is similar to the method used for the last eight decades, except that an attachment is bonded to the tooth, and bone removal and soft tissue excision is minimal. The closed eruption technique, in contrast, has the surgical flap sutured closed after an attachment is bonded on the tooth, with only a ligature wire or gold chain sticking out of the tissue to connect to the elastic force. The wound remains closed as the impacted canine is directed into the arch.

Three papers compared the open eruption technique with the closed eruption technique. In an early publication, Wisth and colleagues[93] compared two groups of patients, all of whom had a Class I malocclusion and required no extractions of permanent teeth. The open eruption group required 18 months of treatment time, while the closed group required 22 months of treatment time. The palatal pocket depth of the closed group was significantly deeper than that in the open group, but the loss of attachment was greater on the palatal side in the open group. The bone height was similar for both groups.

Another group[112] compared only the treatment duration of the two techniques of exposure and found the mean duration to be 28.8 months for both groups. In all subjects, the impaction was categorized by the authors as "intermediate".

In a very recent paper, Burden and his group[113] reviewed the available evidence supporting the two methods of surgical exposure of palatally impacted canines. Their review of the literature failed to produce a clear answer to whether one of the two techniques is better for the long-term health of a palatally impacted canine than the other. The published evidence suggested that repeat surgery can be required with both techniques, but the problem is more often associated with the closed eruption technique, mainly to rebond a loose attachment. The operating time with the closed technique (average time 36 minutes) takes up to three times longer than in the open eruption method (average time 12 minutes). Finally, they found that the delay in applying orthodontic traction often associated with the open technique contributed to a slightly increased period of active orthodontic treatment. This delay in applying traction was usually to allow some free physiologic eruption of the canine to occur before bonding an attachment to the tooth.

1.6.9 - Potential Complications in Treating Palatally Impacted Canines

Studies have indicated ankylosis, loss of attachment, and external resorption as sequelae of orthodontic tooth movement of impacted canines when these teeth are ligated around the cervical area with wire.[21,99] This method of attachment is no longer recommended.

Boyd[96] assessed 20 patients from his own practice, 12 of whom had an attachment direct bonded to the impacted canine, and 8 who had a wire ligated around the cervical area as the method of attachment. All twelve of the direct-bonded patients showed the impacted canine in place at the end of active treatment. In the wire ligation

group, 38% of the impacted canines had to be extracted during treatment due to ankylosis and external resorption. In addition, the mean loss of attachment data showed that the direct-bonded group had no clinically significant loss compared to the control teeth, while the wire ligated group did show a clinically significant difference in attachment loss compared to the control group.

A study[114] examining the periodontal status of palatally impacted canines approximately 2 years after active treatment, all aligned using a band cemented to the impacted tooth and using the closed eruption technique, showed that the mean pocket depth was statistically significantly greater in the previously impacted teeth. As well, bone support around the previously impacted canines was significantly less than the control canines, and the previously impacted canines were generally not as well aligned as the control side canines.

Brezniak and Wasserstein[115] published a literature review of factors affecting root resorption and found that the vast majority of reviewed studies reported that severity of root resorption is directly related to treatment duration. If the treatment of impacted canines does indeed take longer than normal, root resorption of any of the teeth could be a potential complication in treating these cases.

Woloshyn et al[116] examined the pulpal and periodontal reactions to orthodontic alignment of palatally impacted canines. Her group of 32 patients was at least 5 months post-treatment with a mean of 3 years 7 months, and all had a "conservative" surgical exposure with minimal bone removal. These authors found that pocket depths and attachment levels were deeper at the mesial of the previously impacted canine than at

the contralateral control site and crestal bone height was significantly lower on the mesial aspect of the impacted canine and distal aspect of the adjacent lateral incisor. Twenty-one percent of the previously impacted canines showed pulpal obliteration at the recall evaluation with twenty-nine percent failing to respond to an electrical pulp test. The roots of the adjacent lateral incisors and premolars were statistically significantly shorter than the contralateral control teeth. Two examiners, viewing intraoral slides, could correctly identify the previously impacted canine in approximately 74% of the cases, due to its discoloration, rotation or slight malposition. They concluded that the periodontal consequences were clinically minimal as long as the exposure was conservative.

Kuftinec and Shapira[117] mentioned that even if the impacted canine has not damaged the roots of the adjacent incisors when orthodontic treatment begins, the orthodontist must be careful when erupting the canine into the arch to not cause iatrogenic resorption by moving the canine into the roots of the adjacent teeth.

Pearson and associates[118] determined that 30.7% of all cases that were exposed and bracketed at the time of surgery, and erupted into occlusion using the closed eruption method, required a second surgical intervention. Only 15.3% of those cases with simple surgical exposure (open-eruption and free physiological eruption for 6-9 months) required a second surgery. They suggested that simple exposure and some time of free physiologic eruption provides an equally efficient and predictable method of managing the palatally impacted canine with clinical and financial benefits, even though this method required 4 extra months of total treatment time.

In a recent Canadian study of both labially and palatally displaced canines[119], a group of researchers observed 54 patients with 82 impacted canines for 18-30 months after surgery. The 60 palatally impacted canines all utilized the closed eruption technique, and the 22 labially displaced teeth employed either an apically repositioned flap or closed eruption, depending on the initial position of the canine. All of the 82 teeth were successfully brought into occlusion. The only complications included 2 palatal and 1 labial canine debonding during treatment. Clinically, there were no cases of infection, eruption failure, ankylosis, gingival inflammation, or gingival recession once complete eruption was achieved.

1.6.10 - Retention Considerations

Becker et al[114] found a higher incidence of rotations or spaces on the previously impacted side in approximately 17% of the cases, compared to about 9% on the control side.

Woloshyn et al[116] reported noticeable post-treatment changes in the previously impacted canines, such as intrusion, lingual displacement, rotation and discoloration in 40% of these teeth. On the contralateral side, 91% of the teeth were in good alignment.

Clark[82] recommended that lingual drift of a previously palatally impacted canine can be prevented by removing a "halfmoon-shaped wedge" of tissue from the lingual of the now aligned tooth. To prevent rotational relapse of these teeth, or any previously rotated tooth, a circumferential supracrestal fiberotomy (CSF) can be performed, or a permanently bonded retainer can be placed.

1.6.11 - Treatment Duration

Studies[120,121] on the evaluation of factors which affect the duration of orthodontic treatment suggest that treatment time can vary widely between offices and in the same office, depending on the particulars of the individual case. Some of the most important factors which explained the variability in treatment duration include: the number of missed appointments, number of extracted premolars, number of brackets and bands replaced or recemented, the necessity of wearing headgear, and the severity of the malocclusion at the start of treatment. The one study[120] which included impacted canines as a variable had nothing to report on its effect on treatment duration.

Published literature[93,112-114,116,118] suggested that the duration of treatment for orthodontic cases involving palatally impacted canines took an average of 18 months to 30 months, with a wide range for individual cases. None of the above studies used a control group to compare treatment duration of non-impacted canine cases from the various offices used. No literature was found which examined whether the initial position of the canine, or whether unilateral or bilateral, had an effect on the treatment duration.

1.6.12 - Panoramic Radiography

Most dentists or orthodontists first locate the palatally impacted canine on the panoramic radiograph and rate the severity of the impaction using this radiograph. Some of the studies on these teeth also used this radiograph to determine the severity of the impaction; the initial angulation of the impacted canine, the position in relation to adjacent teeth, and the distance from the occlusal plane.[39,111,116] The most common

reference lines, as established by Ericson and Kurol[39], are the occlusal plane as the horizontal line, and the maxillary dental midline as the vertical line. From these reference lines the relative position of the canine is then reported: angularly to the vertical line and the vertical distance in millimetres from the occlusal plane. Additionally, the position of the canine crown medially relative to the adjacent incisor is established. In the late 1940's, Paatero, a Finish scientist, developed the pantomograph for dental use from the medical process of laminography or body section radiography.[122,123] Pantomography or panoramic radiography projects all images onto a single film without superimposition of the mandibular, maxillary and facial structures.[124,125] A recent survey of American orthodontists[126] revealed that 92% of respondents took panoramic radiographs as a routine pre-treatment orthodontic film. The advantages[125] included the broad anatomic region visible on one film, the relatively low radiation dose, and ease and speed with which the radiograph was made. Disadvantages[125] included the lack of fine detail compared to intraoral films, variable magnification and distortion.

Some degree of distortion is inherent in all panoramic radiographs.[127-132] This occurs because each panoramic machine has a focal trough which conforms to what the company considers the ideal dental arch. Differences from this ideal in size and shape of the skull, jaws and teeth, and asymmetries between right and left sides contribute to distortion.

Christen and Segreto[133], in a study with some of the early panoramic machines, found vertical elongation in the premolar, molar and midramus areas, and shortening in

the horizontal dimensions. With the chin raised up 1 cm, the vertical magnification increased slightly but the horizontal shortening was a little less. With the chin lowered 1 cm, there were better results than with the chin raised except in the condylar and coronoid process regions. Moving the chin 1 cm to the right, resulted in an enlarged right side but a decreased left side.

Rowse[128] also investigated the vertical and horizontal distortion in orthopantomograms. He found that different parts of the mandible showed different degrees of magnification and that there was twice as much vertical as horizontal distortion.

In research done with a panoramic machine from the mid-1980's, Larheim and Svanaes[134] found acceptable reproducibility of the left and right sides on images taken at different times, and a consistent 18% to 21% magnification factor for vertical variables. In contrast, they found that measurement of horizontal variables was unreliable because of inconsistent magnification due to a distortion effect caused by both a projection factor and a motion factor.

Common errors made in panoramic radiography are positioning errors and technical errors.[135] Positioning errors occurred with greater frequency than technical errors, with different distortions occurring depending on the error made. The authors emphasized the importance of training in the use of the radiographic equipment to make the best image possible.

In their study, Ursi et al[136] agreed that horizontal measurements are unreliable because they are influenced by a projection factor and a motion factor, but angular

measurements are not so variable. They stated that, for clinical purposes, a 5 degree measurement variation between two exposures is not serious.

Using 10 skulls, Carter and colleagues[137] analysed vertical magnification of the midface. Their results showed that as one moves posteriorly around the arch, the magnification increased, from a factor of 1.12 at the median palatal suture to 1.19 at the first molar. They found that small variations in the magnification factor occur with variations in head positioning but this may not be clinically important if the positioning error is small.

Serman and Buch[138] mentioned how the inherent distortions seen in panoramic radiographs can be used to localize impacted teeth. An impacted canine which appeared larger than the contralateral non-impacted canine lay palatal to the dental arch, while an impacted tooth which appeared smaller and more fuzzy or indistinct on the panoramic image than the contralateral canine was positioned labial to the dental arch.

Comparing the accuracy of images from three different panoramic machines and two lateral oblique projections, Wyatt et al[139] found that more accurate vertical and horizontal measurements can be made from the lateral oblique projections, but the angular measurements were similar between the two different radiographic views. The mean vertical measurement differences ranged from 4mm-6mm for the different panoramic machines, while the mean horizontal differences were only 0.1mm-1.6mm, but with a wide range.

Xie et al[140] assessed whether it was possible to make accurate vertical measurements of the jaws from panoramic radiographs. They took 5 skulls and

radiographed them in different positions: the ideal position, shifted 5 mm forwards and backwards, and tilted up and down 5 degrees. They found that a line joining the articular eminences is unsuitable as a horizontal reference line for measurements in the tooth-bearing areas. A line using the inferior points of the orbits was unsuitable for measurements in the anterior part of the maxilla in the tilted skulls, but was acceptable in the posterior maxilla. Shifting forwards or backwards by 5 mm had little effect on measurements. They recommended a horizontal reference line that is located anatomically directly above or below the point being measured, in the plane of the centre of the image layer. The occlusal plane line, as used to measure the vertical position of an impacted canine, would fit this recommendation. They concluded by stating that a slight misalignment of the head, such as the 5 degrees or 5 mm that they used, does not significantly affect vertical measurements as long as the reference line is in the same vertical plane as the teeth.

In a companion study, Xie et al[141] found that variations in vertical measurements of dentate subjects were small: 9%-11% for the mandible and 6%-11% for the maxilla. They used the inferior points of the orbit as the reference line for the maxillary measurements.

A recent update on dental imaging by Whaites and Brown[142] suggested that patient positioning aids on current panoramic machines, such as light beam marker lines, make the repeatable and proper positioning of the patient much easier and more accurate. Measurements from computed tomography (CT) imaging are significantly more accurate than those taken from a standard panoramic image, however these

machines are currently not priced for purchase by individual practitioners. Digital imaging equipment, which is now available and affordable, will allow a reduction in the radiation dose, and the manipulation and magnification of areas of interest on a radiographic image. This may increase the diagnostic yield available from an image.

The above studies on panoramic machines and images suggested that with proper training and attention to detail, patient positioning can be a repeatable and accurate undertaking. Vertical measurements and angular measurements seem to be more accurate than horizontal ones. It is important to realize that there will be a small magnification and distortion factor, as stated by each manufacturer of individual machines, and this factor will vary somewhat in different areas of the jaw. These small amounts of variation may not be clinically significant in the use of these images for localizing the position of a palatally impacted canine.

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Chapter Two

Research Paper #1

Reliability of Panoramic Reference Lines Used in Describing the Position of Palatally Impacted Maxillary Canines: A Pilot Study

2.1 - Introduction

A recent survey of American orthodontists revealed that 92% of respondents took panoramic radiographs as a routine pre-treatment orthodontic film.[1] Some degree of distortion is inherent in all panoramic radiographs due to differences in size and shape of the skull, jaws and teeth, and asymmetries between right and left sides.[2-8] In the sharply depicted layer of the panoramic radiograph the image will show the same magnification factor for both the horizontal and vertical planes.[9] Objects outside this layer will appear distorted because of a motion factor - the difference between the velocity of the film and the velocity of the projection of the object on the film.[9] Displacement, distortion and magnification can cause changes in the dimensions and position of objects on radiographs compared to the actual object.

A 1968 study using some of the early panoramic machines found vertical elongation in the premolar, molar and midramus areas, and shortening in the horizontal dimension.[10] With the chin raised up 1 cm, the vertical magnification increased slightly but horizontal shortening was less. With the chin lowered 1 cm, there were better results than with the chin raised except in the condylar and coronoid process regions. Moving the chin 1 cm to the right resulted in an enlarged right side and smaller left side. Another investigation into vertical and horizontal distortion in orthopantomograms found that different parts of the mandible showed different degrees of magnification and that there was twice as much vertical as horizontal distortion.[3]

In research done with panoramic machines from the mid-1980's, Larheim and Svanaes[11] found acceptable reproducibility of the left and right sides on images taken at

different times, and an 18% to 21% magnification factor for vertical variables. In contrast, they found that measurement of horizontal variables was unreliable because of inconsistent magnification due to a distortion effect caused by both a projection factor and a motion factor.

Another investigation[12] agreed that horizontal measurements are unreliable because of the influence of the projection factor and motion factor, but angular measurements were not so variable. They stated that, for clinical purposes, a 5 degree measurement variation between two exposures is not serious.

Using 10 skulls, Carter and colleagues[13] analysed vertical magnification of the midface. Their results showed that as one moves posteriorly around the arch the magnification increased, from a factor of 1.12 at the median palatal suture to 1.19 at the first molar. They found that small variations in the magnification factor occurred with variations in head positioning but this may not be clinically important if the positioning error is small.

Xie et al[14] assessed the accuracy of vertical measurements taken from panoramic radiographs. It was found that a line joining the articular eminences was unsuitable as a horizontal reference line for measurements in the tooth-bearing areas. A line using the inferior points of the orbits was unsuitable for measurements in the anterior part of the maxilla in the tilted skulls, but was acceptable in the posterior maxilla. Shifting forwards or backwards by 5 mm had little effect on measurements. These authors recommended a horizontal reference line that is located anatomically directly above or below the point being measured, in the plane of the centre of the

image layer. The occlusal plane line when used to measure the position of an impacted canine would fit this recommendation. They concluded by stating that a slight misalignment of the head, such as the 5 degrees vertical tipping or 5 mm transverse movement that they used, does not significantly affect vertical measurements as long as the reference line is in the same vertical plane as the teeth.

Common errors made in panoramic radiography are positioning errors and technical errors.[15] Positioning errors occurred with greater frequency than technical errors, with different distortions occurring depending on the error made. A recent update on dental imaging suggested that patient positioning aids on current panoramic machines, such as light beam marker lines, make the repeatable and proper positioning of the patient much easier and more accurate.[16]

Most dentists or orthodontists first locate a palatally impacted canine on a panoramic radiograph and assess the severity of the impaction from this radiograph. This assessment often determines whether to extract the impacted canine or attempt to orthodontically bring it into occlusion. Some investigators who studied impacted canines used this radiograph to determine the severity of the impaction and to describe the initial angulation of the impacted tooth, the horizontal position in relation to adjacent teeth, and the vertical distance from the occlusal plane.[17-19]

Common reference lines used in studies of impacted canines, as established by Ericson and Kurol[17], are the occlusal plane as the horizontal line, and the midline of the maxillary central incisors as the vertical line. From these reference lines the relative position of the canine is reported; the angle of impaction relative to the vertical line,

position of the crown medially relative to the adjacent incisor, and distance from the occlusal plane.

The objective of this panoramic radiographic study was to determine what effects 5^{o} rotations of dried skulls about vertical and horizontal axes would have on a metal marker affixed to the palate in the approximate position of an impacted maxillary canine. The occlusal plane and a vertical line bisecting the long axes of the maxillary central incisors were used as reference lines. The repeatability and reliability of these reference lines in studies of impacted canines have not been previously reported.

2.2 - Materials and Methods

A sample of 5 adult dry skulls with intact maxillary dentitions was obtained from the collection of the Faculty of Medicine and Dentistry at the University of Alberta. A metal marker in the shape of a cross, fabricated from .036 inch orthodontic wire, was temporarily affixed to the skulls on the right palatal side of the maxilla in the approximate location that an impacted canine would be located. All of the panoramic radiographs were made in the Division of Radiology at the University of Alberta. Each skull was stabilized in the headholder of a Siemens Orthophos 100 orthopantomographic machine (Siemens Corporation, Iselin N.J.) with the radiation beam attenuated to provide an acceptable exposure of the dried skulls. Each skull was radiographed five times, once in each of five different positions. The initial radiograph was made with the skull's Frankfort horizontal plane aligned with the horizontal light beam marker of the panoramic machine, the midline of the skull aligned with the vertical light beam marker, and the maxillary central incisors placed into the bite tab of

the machine (the ideal view). Radiographs were then taken with the skull rotated 5° up and 5° down (up and down views) while keeping the midline of the skull on the vertical light beam marker. Two additional radiographs were made with the skull rotated 5° to either side about a vertical axis (left and right views) while keeping Frankfort horizontal aligned with the horizontal light beam marker of the panoramic unit. These 5° rotation marks were previously placed on the skulls with a removable marker using a standard protractor. Foramen magnum was used as the vertical axis centre of rotation, while the external auditory meatus was used as the horizontal axis of rotation. In order to minimize movement of the skull within the head holder of the panoramic unit the ideal view was always done first, followed by the vertical projections. The left and right views were done last. Each radiograph was processed and labelled before the next projection was taken.

These five different radiographic projections of each of the five skulls were viewed under standardized conditions and traced onto acetate overlays using a 0.3 mm diameter lead pencil. Each radiograph was traced and measured twice, at least one week apart, by the principal investigator.

On each tracing the occlusal plane reference line was drawn, connecting the mesiobuccal cusp of the maxillary first permanent molar and the incisal edge of the maxillary central incisor on the side that the metal marker was placed. A vertical reference line was drawn bisecting the long axes of the two maxillary central incisors (Figure 2.1). From these two reference lines linear measurements were made using electronic calipers accurate to 1/100 of a millimetre (Digimatic Caliper, Mitutoyo

Corp., Japan), and angular measurements were made using a protractor accurate to 1°.

Four linear and two angular measurements were performed. Using the occlusal plane reference line, measurements were made vertically along the long axis of the metal marker to the closest point of the metal marker and the furthest point of the metal marker. Two separate measurements were done to determine whether a larger distance from the reference line would show a different error than a shorter distance. From the vertical reference line, two horizontal measurements were made along the horizontal long axis of the metal marker to the closest and furthest points of the metal marker. In addition, angular measurements were made using the vertical reference line and both the horizontal and vertical portions of the metal marker. (Figure 2.1)

Subsequently, the radiographic distortion for the different measurements with different head rotations was calculated. The measurements with the skulls placed in the ideal position were established at 100%, and distortion factors for the different skull positions were calculated. (Table 2.3)

2.3 - Statistical Analysis

All twenty-five radiographs were used for statistical analysis using the SPSS 9.0 statistical package (SPSS for Windows, SPSS Inc, Chicago, Ill). To determine the tracing and measurement error of the linear and angular variables, all radiographs were randomly traced twice and each tracing was measured twice. The average measurement value and standard deviation of each linear and angular measure was determined over the four repeated measurements. Subsequently, the mean standard deviation of each linear and angular variable for all five skulls was calculated using 25 measurements –

the 5 different skulls and 5 different positions (Table 2.1). The mean differences of the measurements between the different rotations of the skulls were calculated and the statistical significance of these differences was assessed using a paired two-tailed t-test (Table 2.2). Significance levels less than 5% were considered to be statistically significant.

2.4 - Results

Descriptive data for the mean values and standard deviations (SD), paired t-tests and p-values, and distortion factors for the different variables can be found in Tables 2.1 through 2.3. The t-tests revealed that there were significant differences in the values of some linear and angular variables for different 5° rotations of each skull when compared to a properly placed skull.

The variable 'Horizontal 1' did not show any statistical differences in the measurements for the different positions. The 'Vertical Angle' and 'Vertical 2' variables had the greatest amount of measurement variation with 7 of the 10 positional comparisons showing a statistically significant difference. Generally, any comparison between a right rotation and any other rotation showed a significant difference in the measurement values. The largest measurement difference tended to be between the left and right positions, with the ideal/down comparison generally showing the smallest measurement variability.

Table 2.3 shows the distortion factors of different positions for the different variables compared to the value for the ideal position. These values are not to be confused with the amount of magnification which actually occurs on the panoramic

radiograph in the anterior area. These distortion factors are only in comparison to the value of the measurement when the skull is properly placed in the radiographic machine.

Generally, a left rotation resulted in a slight increase in the measurement values while a right rotation resulted in a decrease in the values. The vertical movements commonly showed smaller variability in their values compared to the value in the ideal position than the left and right rotations did.

2.5 - Discussion

The purpose of this study was to determine if various measurements done in the anterior maxilla in the approximate location of a palatally impacted canine, employing reference lines used in other studies involving impacted maxillary canines, will be reliable even with small rotations of the head in the panoramic machine. It was not the purpose to determine the amount of actual magnification which may occur in the anterior maxilla in panoramic radiographs. Because it was a pilot study, the number of subjects was small and should be kept in mind when interpreting the results. Another limitation was that the metal marker was placed on the palatal surface of the maxilla and not inside the alveolus where an actual impacted canine would be located. This could have an affect on the magnification and measurements involved as the marker may have been outside the focal trough, which would result in more blurring, distortion and magnification than objects within the focal trough.[20]

When an object is placed perpendicular to the central ray of the radiographic tube, its projected height in a panoramic radiograph is at a maximum.[21] When the same

object is inclined towards the film or towards the tube, its projected height will change non-linearly with respect to the angle of the tilt.[21] Similarly, when an object is horizontally rotated towards or away from the film in a panoramic machine, its position will appear to change on the radiograph depending on the direction of head rotation. Xie et al[14] have suggested that vertical measurements in the anterior maxilla from reference lines which are not in the same vertical plane as the anterior maxillary teeth, such as from a line joining the articular eminences or one joining the zygomatic arches, are sensitive to up/down tilting of the skull. Horizontal measurements on panoramic radiographs are not reliable when compared to the actual measurement due to a distortion effect caused by a projection factor and a motion factor.[11] Carter et al[13] found that small variations in the magnification factor occur with variations in head positioning but that this may not be clinically important if the positioning error is small. Angular measurements have shown less variability on panoramic radiographs compared to linear measurements.[11,12,22]

In this study the only variable which did not show any statistical difference of the means for any of the skull positions was the linear measure 'Horizontal 1'. In general, the further the linear distance to the point of interest, the more the measurements varied for the different skull movements. In all cases, except 'Horizontal 1' and 'Horizontal Angle', there was a difference in the measures between the left and right skull rotations. The horizontal measurements were generally greater as the skull was rotated to the left and smaller with a right rotation, compared to the ideal position, especially with the larger distances of 'Horizontal 2'. This occurred because the metal

marker, which was placed on the right side of the maxilla in all five skulls, was magnified in size with a right rotation and would thus appear closer to the midline. The opposite effect occurred with a left rotation where the metal marker appeared to be decreased in size and further from the midline. The 10° difference between a 5° rotation right and a 5° rotation left would be expected to cause a variance in the measurements due to the different magnification which would occur with the different skull positions. The distance for the 'Horizontal 1' measurement is small and was not as affected by magnification as much as the longer distance for the 'Horizontal 2' measurement, where the measurement point was in a different part of the maxilla. This agreed with studies which found that different parts of the jaws have different magnification factors.[3,11,13]

Similarly, values between the vertical movements might be expected to show variability, especially for the vertical variables measured, due to the 10° change in skull position. It was found that 'Vertical Angle' and the large distance in 'Vertical 2' do indeed show a statistically significant difference in their measures with the different skull rotations. The shorter distances involved in 'Vertical 1' did not show a statistically significant difference but generally showed a trend, with a larger value for the down position and a smaller value for the up position.

Angular measurements of the vertical marker (Vertical Angle) appeared to be more affected by head movements than those of the horizontal marker (Horizontal Angle), with more of the Vertical Angle measures showing significant differences from each other. This may be due to the vertical part of the marker being in the area of the

canine, which has a different magnification factor than the central incisor area where the reference line was situated.[13]

Measurement differences between the ideal position and the down position were not significantly different for any of the linear or angular variables. This was in agreement with Christen and Segreto[10] who found that distortions were generally less with a slight (1 cm) downward position of the chin compared to a slight upward position of the chin.

Xie et al[14] have recommended a horizontal reference plane located directly above or below the point being measured. The metal marker in this study was palatal to the teeth used as points for the horizontal reference line, therefore additional error, compared to measurements of an actual impacted canine which would be closer to the plane of the line of reference and the focal trough of the panoramic machine, could have been introduced.

With only one exception, the standard deviations of the averages of linear measures were less than 10% of the total value, and the angular variables less than 3° (Table 2.1). For clinical purposes, a variation in measurement of up to 5° between two exposures is not considered serious.[3,7,12] The mean difference of the measurements for the different variables measured, between the different skull positions, generally varied by less than 1 mm for the shorter distances and less than 3 mm for the longer distances, with the angular differences generally less than 3° (Table 2.2). As seen in Table 2.3, the distortion of the measurements with slight skull rotations commonly varied by 10% or less compared to the measurements on an ideally positioned skull. In the context of